Expert System for Group Technology

M. Srinivasulu and Shravan Kumar
University of Roorkee, Roorkee - 247 667

ABSTRACT

An expert system for solving group technology (GT) problems has been developed, considering simplified models of industrial GT problems. It solves problems of varying characteristics using in-built algorithms, namely average linkage clustering algorithms (ALC), cluster identification algorithms (CI) and generalised *p*-median model. Depending upon the characteristics of GT problem, a suitable algorithm is selected. The algorithm takes the required inputs for the problem and gives the output, which consists of machine cells with corresponding part families and the bottleneck parts, if any.

1. INTRODUCTION

Group Technology (GT) is defined as a disciplined approach to identify things as parts, processes, equipment, tools, people and customer needs by using their attributes (like visual, mechanical, functional or environmental). These attributes are then analysed to identify similarities among the things; the things are grouped into families according to similarities and these similarities are used to increase the efficiency and effectivenéss of manufacturing process. The concept of GT was first introduced by Mitrafanov. Burbidge[1], one of the pioneers of GT, used it in developing the concept of production flow analysis. Hitomi, *et al*[2]. have done considerable research in GT and extended its scope to entire production management. In addition, considerable research has been done in this field to make GT a universally accepted philosophy for flexible manufacturing system (FMS) and computer integrated manufacture (CIM) applications.

This paper deals with an expert system which solves the GT problem with varying characteristics using Cluster analysis algorithms. The system is based on the idea suggested by Kusiak[3]. Though the system can be used for various attributes, the discussion proceeds taking into consideration the machine attribute of the part.

2. FEATURES OF THE PROBLEM

The grouping process of machines and parts is simple when the number of machines and parts is small. But, it becomes impossible to solve the problem manually when their number increases to tens and hundreds. In industry, we generally deal with the later type of problems. Cluster analysis used for problem solving is concerned with grouping of objects into homogeneous clusters based on object attributes. The method initially requires modelling the problem and then solving this model using a particular method. Three types of model formulations are used.

Received 28 October 1996

2.1 Matrix Formulation Methods

These methods are production flow analysis[1], similarity coefficient methods[4,5], cluster identification algorithm[6] and others. Here a machine-part incidence matrix (A) is constructed. The machine-part incidence matrix consists of 0.1 entries, where an entry 1(0) indicates that machine, row, is used (not used) to process part, column, j.

2.2 Mathematical Programming Formulation Methods

These methods are generalised *p*-median model[7], quadratic programming model and fractional programming.

2.3 Graph Formulation Methods

These methods are bi-pariate graph, transition graph, boundary graph methods. They are suitable for a particular type of problem and each has a different computational complexity. Based on the above analysis, the features of a GT problem are:

(a) Huge amount of data,

(b) Possible formulation in a number of ways, and

(c) Variation in the computational complexity of these formulations.

These types of problems are most suitably solved using expert system approach[8]. The system handles the data and uses the advantages of available model and algorithms.

3. SYSTEM ARCHITECTURE

A rule-based system architecture as suggested by Kusiak is used (Fig. 1). The architecture includes an expert system which gathers data about machines and parts (machine-part incidence matrix), cost (in case it is being considered) and constraints, like number of clusters. The expert system analyses a GT problem (data) and depending upon its type and size, an appropriate

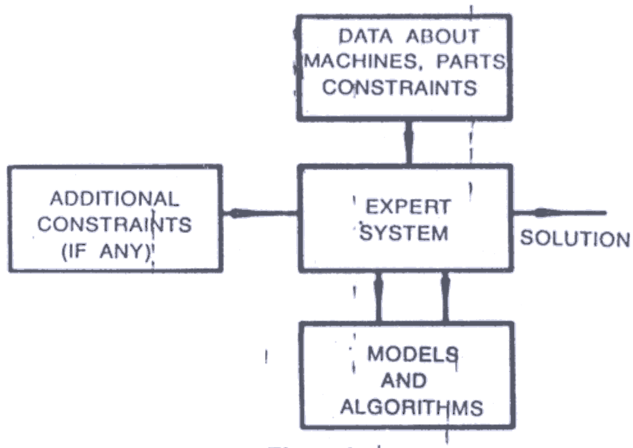


Figure 1.

model and algorithm is selected. Based on the type of algorithm selected, it poses questions regarding additional constraints if the user intends to have any (this facility is available only for one of the algorithms used).

4. MODELS & ALGORITHMS

For each of the three different formulations mentioned in the features section, the following three characteristics have been considered for selecting an algorithm:

(a) Limited number of part families (or machine cells),

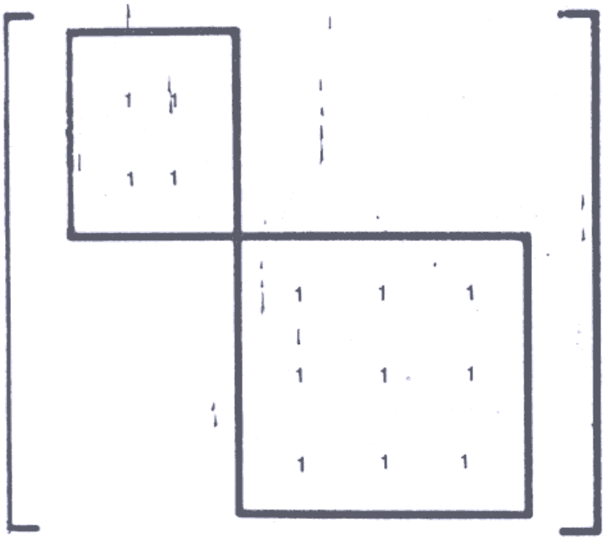
(b) Limited number of parts in each part family, and

(c) Costs (e.g., subcontracting, production)

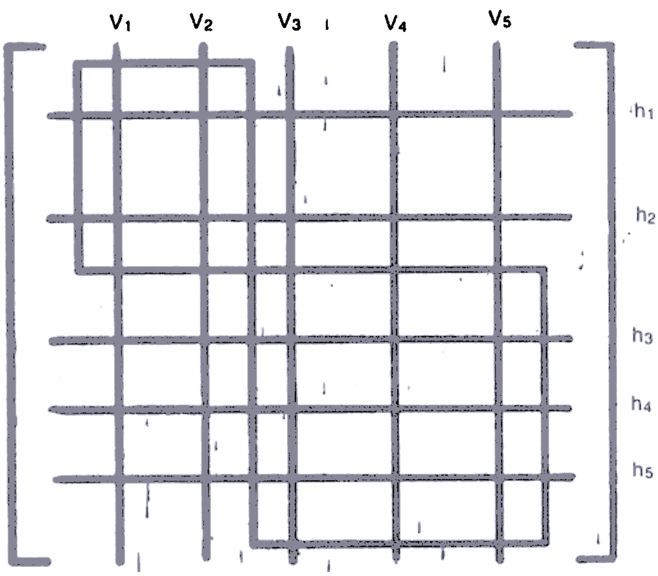
4.1 Extended Cluster Identification Algorithm

It is a heuristic method of GT problem solving developed by Chow and Kusiak[6]. This method is used by the system when the user is choosy about the contents and the number of part families. It is the case where the additional constraints block shown in Fig. 1 comes into role, and the constraints are fed by the user. The algorithm can be used with or without consideration of subcontracting costs. Its input is machine-part incidence matrix and cost matrix.

Consider an ideally clustered-binary matrix, (1).



Crossing all entries in the matrix (1) by five horizontal lines and five vertical lines results in matrix (2).



One can notice that matrix (2) has the following property: Each entry '1' in a cluster is crossed exactly by two lines (a horizontal and a vertical) belonging to this cluster. For example, all entries of '1' in the upper left corner cluster in matrix (2) are crossed by exactly two vertical lines $v1$, $v2$, and two horizontal lines $h1$, $h2$ This property is used to develop the cluster identification algorithm. This concept of the algorithm was developed by Iri, which was the principle for the present algorithm.

$A^{(k)}$ is the machine-part incidence matrix after k iterations.

Algorithm

Step 0.

Set iteration number $k =$

Step

Select those machines (rows of matrix A) that, based on user's knowledge, are potential candidates for inclusion in machine cell, MC-k. Draw horizontal lines h_i through each row of matrix $A^{(k)}$ corresponding to these machines. In the absence of the user's expertise, any machine can be selected.

Step 2.

For each column in $A^{(k)}$ corresponding to the entry of 1 crossed by any of the horizontal line h_i, draw a vertical line v_j.

Step 3.

For each row in $A^{(k)}$ corresponding to the entry of 1 crossed by any of vertical lines v_j, drawn in Step 2, draw a horizontal line h_i.

Based on the machines corresponding to all the horizontal lines drawn in Step 1 and Step 3, a temporary machine cell MC-k is formed. If the user's expertise indicates that some machines cannot be included in MC-k, erase the corresponding horizontal lines result in MC-k. Delete from matrix $A^{(k)}$ parts (columns) that are to be manufactured on at least one of the machines already included in MC-k. Place these parts on the list of parts to be manufactured in a functional machining facility or subcontracted. Draw a vertical line v_j through each crossed-once entries of 1 in matrix $A^{(k)}$ which does not involve other machines than those included in MC-k.

Step

For all the crossed-twice entries of 1 in $A^{(k)}$, form a machine cell MC-k and a part family PF-k.

Step 5.

Transform the incidence matrix $A^{(k)}$ by removing all the rows and columns corresponding to MC-k and PF-k.

Step 6.

If matrix $A^{(k+1)} = 0$ (where 0 denotes a null matrix), stop; otherwise set $k = k + 1$ and go to Step 1.

When cost is to be considered, with each column of the machine-part incidence matrix A and c_j of part j is associated. In this case, the contents of part families are such that costs in handling the bottleneck parts are minimum. Different solutions are obtained by selecting a different starting row in Step 1 and for each solution, the costs are compared.

4.2 Average Linkage Clustering Algorithm

This is developed by Seifoddini and Wolfe[4] as an extension to single linkage cluster analysis (SLCA) algorithm developed by Mc Auley[5], so as to find independant clusters and bottleneck parts. It is used by the system when there are no constraints regarding the number and contents of the part family and cost is not a consideration. The SLCA is based on the similarity coefficient s_{ij} measure between two machines i and j and is computed as

$$S_{ij} = \frac{\sum_{k=1}^{n} d^1(a_{ik}, a_{jk})}{\sum_{k=1}^{n} d^2(a_{ik}, a_{jk})} \qquad (3)$$

where

$$d^1(a_{ik}, a_{jk}) = \begin{cases} 1, \text{ if } a_{ik} = a_{jk} = 1 \\ 0, \text{ otherwise} \end{cases}$$

$$d^2(a_{ik}, a_{jk}) = \begin{cases} 1, \text{ if } a_{ik} = a_{jk} = 1 \\ 0, \text{ otherwise} \end{cases}$$

a_{ij} = Element of matrix A

To solve the GT problem using SLCA, similarity coefficients for all possible pairs of machines are computed. Machine cells are generated based on a threshold value of the similarity coefficient. A disadvantage with SLCA is that it requires a threshold value; otherwise it fails to recognise the individually separable clusters resulting from eliminating bottleneck machines. To recognise the bottleneck machines, Seifoddini and Wolfe[4] used the average linkage clustering. They defined the similarity coefficient between any two clusters as an average of the similarity coefficient between all members of the two clusters. The total number of intercellular movements (ICM) between two machine cells is computed as

$$ICM_{ij} = \sum_{k=1}^{n} d^3(V_{ik}, V_{jk}) \qquad (4)$$

where

$$V_{ik} = \begin{cases} 1, \text{ if } \sum \quad a_{ik} \neq 0 \end{cases}$$

$$d^3(V_{ik}, V_{jk}) = \begin{cases} 1, \text{ if } V_{ik} = V_{jk} = 1 \\ 0, \text{ otherwise} \end{cases}$$

When $d^3(V_{ik}, V_{jk}) = 1$, it indicates that part k requires processing in both machine cells MC-i and MC-j and thus part k is a bottleneck part. This problem can be solved either by removing part k from the two machine cells or by adding an identical machine to each machine cell.

4.3 Generalised p-Median Model

This model is an extension of the p-median model and it considers different process plans for producing a part[9]. So in the machine-part incidence matrix for every part, more than one column is used, each corresponding to a different process plan. The system uses this algorithm if one wants to choose best process plan among different alternatives. The model requires the number of process families (p) at start. If p is not known, then it starts with a small number of process families $p = p_o$ and solves the model. If the quality of process families is not satisfactory, p is increased by 1, and model is again resolved. The model can work taking into consideration the costs. The integer programming model for this is as

Notations

- n Number of parts
- q Number of process plans
- F_k Number of process plans for part k, $k = 1,2,3....n$
- p Required number of process families
- d_{ij} Distance measure between process plans i and j.

Hamming distance measure

$$d_{ij} = \sum_{k=1}^{n} z(a_{ik}, a_{jk}) \tag{5}$$

where

$$z\,(a_{ik}, a_{jk}) = \begin{cases} 1, & \text{if } a_{ik} \neq a_{jk} = \\ 0, & otherwise \end{cases}$$

Model

The objective function minimises the total sum of distance measures and production costs.

$$\min \sum_{i=1}^{q} \sum_{j=1}^{q} d_{ij} x_{ij} + \sum c_j x_{ij} \tag{6}$$

such that

$$\sum_{i \varepsilon F_K} \sum_{j=1}^{q} x_{ij} = 1 \text{ for all } k = 1, 2....n \tag{7}$$

$$\sum_{j=1}^{q} x_{ij} = p \tag{8}$$

$$x_{ij} \leq x_{jj} \text{ for all } i = 1,2 \dots q \text{ and } j = 1,2 \dots q \tag{9}$$

$$x_{ij} = 0,1 \text{ for all } i = 1,2 \dots q \text{ and } j = 1,2 \dots q \tag{10}$$

One constraint[7] ensures that for each part only one process plan is assigned to a part family. Another constraint[8] specifies the required number of part families[7] which ensures that part family i belongs to part family j only when this part family is formed. The third constraint[9] ensures integrality.

5. WORKING OF THE SYSTEM

The present system can be used to solve a large scale GT problem in a sufficiently less time. The formulations used in this paper are simplified models of the industrial GT problem. The system poses a questionnaire to the user so as to gather characteristics mentioned in models and algorithms section. The selection of the model depends on the characteristics of the problem to be solved and the selection is shown in Table 1.

Table 1

Limited number of PF's	Choose contents of PF	Cost considered	Model	Inputs
No	No	No	ALC	A
No or Yes	Yes	No or Yes	CI	A.C.P'
No or Yes	No	No or Yes	Gen. P**	A.C.P

* = Additional constraints can be given interactively.

** Gen.p = Generalised p-median model.

p in the second and third cases is optional.

After determining the model to be used, the algorithms mentioned above are used for solving the problem taking the inputs given in Table 1. The algorithms are developed in C-language.

5.1 Trial Run

When input were $p = 2$

$$\begin{array}{l} \text{Part number} \\ \begin{array}{ccccccccccccc} & \multicolumn{3}{c}{1} & \multicolumn{2}{c}{2} & \multicolumn{2}{c}{3} & \multicolumn{2}{c}{4} & \multicolumn{2}{c}{5} & & \\ \end{array} \\ \text{Process plan number} \\ \begin{array}{c|ccccccccccc|cl} & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 & 11 & & \\ & & & 1 & & 1 & 1 & & 1 & 1 & & 1 & 1 & \\ A = & & 1 & & & & & 1 & & & & & 2 & M/C \\ & & & & 1 & & & & & 1 & 1 & & 3 & Number \\ & 1 & 1 & & & & 1 & 1 & 1 & & 1 & & 4 & \\ C = & 1 & 1 & 1 & 1 & 1 & 1 & & 1 & 1 & 1 & 1 & & \end{array} \end{array}$$

The solution given is

$PF\text{-}1 = \{2, 7\}$ $MC\text{-}1 = \{2, 4\}$

$PF\text{-}2 = \{5, 9, 1\}$ $MC\text{-}2 = \{1, 3\}$

6. CONCLUSION

This expert system has been developed considering simple models of industrial GT problem. An actual problem has many other additional constraints, like processing time available at each machine, frequency of trips of material-handling carriers, dimension of the machine cell, etc, which were not considered. The system can be further developed considering these constraints so as to make it more realistic.

REFERENCES

1. Burbidge, J.L. Simplification of material flow system. *Int. J. Prod. Res.*, 1982, **20**(3), 339-47.
2. Ham, I.; Hitomi, K. & Yoshida, T. Group technology application to production management. Kluwer Nijhoff Publishing.
3. Chow Wing, S. & Kusiak, Andrew. Decomposition of manufacturing systems. *IEEE J. Robot. Auto.*, 1988, **4**(5), 457-71.
4. Seifoddini, H. & Wolfe P.M. Application of the similarity coefficient methods in GT. *IEEE Trans.*, 1986, **18**(3), 271-77.
5. Auley, J. Mc. Machine grouping for efficient production. *Production Engineer.* 1972, **53**, 271-77.
6. Chow Wing, S. & Kusiak, Andrew. An efficient cluster identification algorithm. *IEEE Trans. Syst. Man and Cybern.*, 1987, **SMC-17**(4), 696-99.
7. Kusiak, Andrew. The generalised GT concept. *Int. J. Prod. Res.*, 1987, **25**(4), 561-69.
8. Kumaran S.R.T *et al.* Expert systems in industrial engineering. *Int. J. Prod. Res.*, 1986, **24**(5), 1107-25.
9. Kusiak, Andrew. Intelligent manufacturing system. Prentice Hall International, 1990, pp. 206-46.